2016 Master Thesis

STUDY ON STORM RUNOFF MODEL CONSIDERING HOUSE RAINWATER DRAINAGE SYSTEM FOR A SMALL URBAN WATERSHED IN SWEDEN

(スウェーデンの都市小流域における各戸雨水排水システムを考慮した洪水流出解析モデルに関する研究)

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Tokyo Metropolitan University

Department of Civil and Environmental Engineering

15885407 Yoko Kai

(Supervisor Prof. Akira Kawamura)

Chapter 1

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Chapter 1 INTRODUCTION

1.1 Background

The city of Arvika in Sweden has experienced severe basement flooding problems in recent years. For example, in summer 2006 a high-intensity storm event in Arvika caused street flooding and 30-40 basements were damaged [1)]. These are expected to further increase as a consequence of climate change and the associated increase in rainfall. The annual rainfall in Sweden is around 600 mm, the 60-minutes design storms with a return period of 10 years representing is 24 mm. These rainfall characteristics in Sweden reflect that the street inlets have not been set basically and most of the rainwater has flow into rainwater pipe through the street inlets directly[2)]. With climate changing and the increase of the rainfall, it is necessary to concern how to deal with the flood damage increasing in urban watershed.

The urban environment is characterized by its abundance of impervious surfaces (roofs, roads, parking lots etc.), from which runoff is rapidly generated as overland flow. Under normal conditions, this flow enters the sewage system to finally be drained to a receiving watercourse, typically a river or an open channel. If the generated runoff exceeds the storage capacity of the sewage system, surface flooding is caused by excess water outflowing from manholes and inlets. The flooding may be exacerbated by a simultaneous overflow of the receiving watercourse.

In order to evaluate the inundation risk of houses with a storm runoff analysis model, the drainage condition of rainwater around building should be modeled in detail. In other words, for calculating the effective rainfall, not only need to make flexible use of the detailed land use data, but also need to check if the rainwater from houses flows to the lots or spills over outside from rainwater drain pipe. Especially the location of street inlets which connects with the rainwater drain pipe. These details are very important to analyze by applying with storm runoff model.

In this study, a storm runoff model considering houses rainwater drainage which is set-up based on so-called urban landscape GIS delineation that faithfully describes the complicated urban land use features in detail[3)]. It is application for a small urban watershed in Sweden. It was evaluated and examined the usefulness of the proposed model by comparing the previous models.

1.2 Past research and the position of this research

Many storm runoff simulation models for urban catchment have studied conducted the research adopting to WASSP, SWMM, MOUSE which targeted to rainwater pipeline or used SMPT Model targeting to hydrologic circulation analysis in urban catchment and so on[1)].

Besides, in the flood runoff process, the simulation model which is added to infiltrate phenomenon always use the Two-dimensional Inundate Analysis Model to simulate the overflow from pipeline which is based on rainwater sewer pipe conduit model like SWMM. However, in order to evaluate the risk of flooded houses, we should estimate the effective rainfall, rainwater on the ground surface and the trend of rainwater pipeline as accurately as possible. Unfortunately, this kind of model has not been developed.

Propose of this study is that, built a storm runoff model which considering house rainwater drainage system for a small urban watershed. Firstly, flexible use of TSR Model. Then application for a small watershed in Arvika by using the data got by field observation. Lastly, the effectiveness of the proposed model is illustrated by comparing the previous model. Input the data of flood event in Sweden in 2006.

1.3 Structure of this thesis

This thesis is composed of five chapters.

Chapter 1 is the introduction which contains the background, motivation, and the objectives of the study. A comprehensive review of literature and a description of the scope and methods are presented in this chapter.

Chapter 2 is talking into account the past research, the storm runoff model and ArcGIS that we use in this study. The storm rainfall model is used in this research, considering the houses, so-called called Tokyo Storm Runoff (TSR) Model, which could simulate urban storm runoff and flood inundation with a vector-based watershed description. It is can exactly delineated the pervious and impervious land surface features with configuration of the using data and software ArcGIS. This chapter also explains the important formulas used in TSR Model and describes the purpose of this study.

Chapter 3 shows the specific information of Arvika in Sweden. The observed and data were given through the photos and maps from the field observation. We described the Sewer characteristic of the sewer system in Arvika. At first, it narrates the basis information of the watershed Arvika, showing the poor drainage facilities which caused inundation in urban watershed. Secondly, it describes the characteristics of sewer pipeline system and inlets condition, and analyzes to answer the question why it is very necessary to reproduce the flood occurrence process as faithfully as possible. Thirdly, some photos and specific information from field observation were exhibited. These information and data were used while we have built the advanced urban landscape delineation. At last, the charter shows the each data of the model which includes Fundamental urban landscape GIS delineation, advanced urban landscape GIS delineation having the Land use feature elements, Rainwater sewer pipe conduit elements and the urban landscape GIS delineation has been built with figures and the number of each element.

Chapter 4 contains the important parameters of this storm runoff model and application to the study watershed in Arivika (Sweden), compiling the results obtained by this simulation. In this application, there are three cases which are Case A, Case B and Case C. The proposed model with the condition by consider about street inlets of ground surface, the previous model which does not consider the street inlet when the rainwater flow out from houses to rode. At first, from the analysis the result, we got each case. Then, we were exhibited the overhead flooding area of ground surface. Secondly, we discussed that, with the results by the parameter operation it shows the results generated each previous model and the proposed model. In this study, by analyzing the result, the relationship between the increase of the rainfall and the risk of the inundation, the relationship of each case, especially the relationship between the street inlets and the discharge in urban area are described. Even if the discharge of surrounding building is over 0.1 m, the risk of basement flood will increase or not change. Finally, evaluation according to the state and the future 10-year probability rainfall. In this part, by comparing the 10 years probability rainfall current situation (TC) to future situation (F3) of the study watershed to get the runoff characteristic of rainfall in the future. Besides, according to rainfall probability now days and 10 years in the future, the change of rainfall and the increase number of overflow manhole are evaluated and examined.

Chapter 5 contains a summary and a concluding discussions of the research. We described the results obtained through this study are summed and describe about the outlook for the future challenges.

Reference for chapter 1

1) Amaguchi, H, Kawamura.A, Olsson, J, Nakagawa, N.: Analysis of climate change impact on urban runoff in Arvika, Sweden by the Tokyo Storm Runoff Model.
2) H. Amaguchi, A. Kawamura, J. Olsson, T. Takasaki, N. Nakagawa: A proposal of storm runoff model considering rain drainage of a house and its application for a small urban catchment
3) H. Amaguchi, A. Kawamura: Development of a storm runoff model considering process of individual building inundation

Chapter 2 STORM RUNOFF MODEL CONSIDERING HOUSE RAINWATER DRAINAGE SYSTEM

2.1 House rainwater drainage system

House rainwater drainage system have 2 conditions. If the houses have connection between houses to the sewer pipe, the rainwater from houses will flow to the sewer directly. If not, as the left side of Fig.2-1, some of the rainwater from houses going to the pervious, the other going to the ground, road, the through the street inlets flow to the sewer pipe.

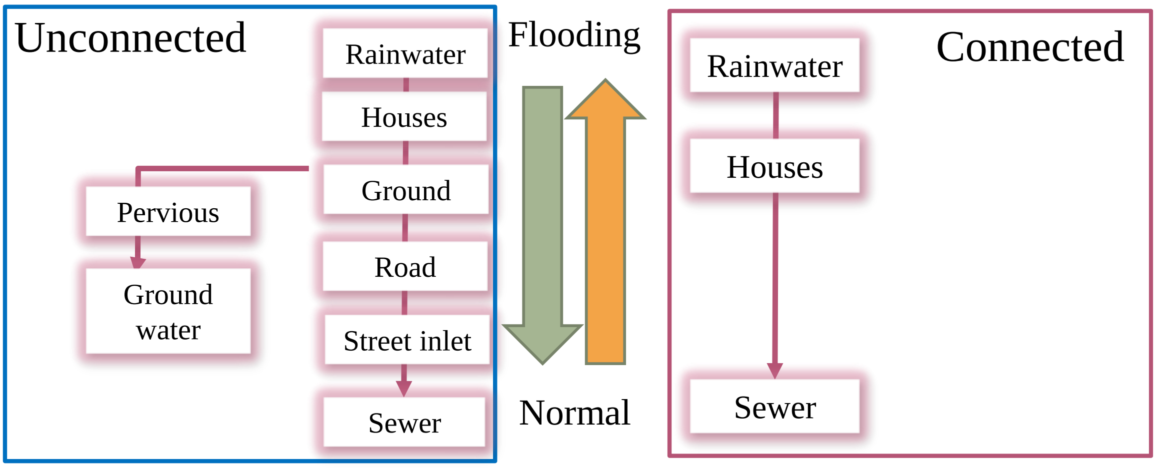

Fig.2-1 House rainwater drainage system

When rainfall begins, water falling on land use segments inside a block or a road forms pools, whereas water falling on a river adds to the river discharge. Rainfall excess from blocks flows out directly or indirectly through different types of surfaces and finally out into the road. When a manhole exists inside the surface, water flows through it to the rainwater sewer pipe conduit. In a manhole, the water level is obtained considering the inflow from the surface together with the upstream inflow from connected pipe conduits. In a pipe conduit, the water flow is obtained considering the water levels in the manholes located upstream and downstream, respectively. When the water level in a manhole exceeds ground level, water flows out and inundates the associated surface segment. The inundated water flows to adjacent surface segments until a manhole that has not reached full inflow capacity is found. The water in the sewer pipe conduits eventually reaches the river channel, which finally drains in the catchment outlet.

In the past simulation, in order to simulate the storm runoff the past simulation model set all the houses connect to the sewer pipe. Regard manholes as rainwater inflow-hole to the sewer pipe. Because of very difficult to get the data, it's also not be considered the existence of lateral sewer. So the problem in the past simulation model, it's very hard to know the exactly connection between houses to sewer and detail storm drainage information, so that they have limited access to simulate house inundation.

2.2 TSR Model (Tokyo Storm Runoff Model)

The recent advances in GIS technology as well as data availability open up new possibilities concerning urban storm runoff modeling[1]. In this study, the simulation model we used is Tokyo Storm Runoff (TSR) Model which can simulate urban storm runoff and flood inundation with a vector based watershed description, it could exactly delineated the pervious and impervious land surface features. Based on urban landscape GIS delineation that faithfully describes the complicate urban land use feature in detail. While we built the data of TSR Model, with the reference to the aerial photograph and ground level data, we divide the urban environment into its smallest, perfectly homogeneous elements which including sewer network system that are hydraulically connected. Especially modeling these impervious area to physically reproduce the storm drainage route. The features of TSR Model is that, it could simulate land use data with minimum unit in TSR Model. What else, it establishes the relationship with land use (especially the houses in this study) and hydrology characteristics explicitly. And built the correspondence relation between sewer pipe and road.

The flow between single spatial elements is based on established hydraulic and hydrological models with equations that describe all aspects of storm runoff generation in an urban environment. To setup the TSR model for Arvika in Sweden, three kind of data are used. The three figures showing the sewer system, surface elevation and surface information.

Fig.2-2 shows the difference between the original data and the data we built in this study. The figures are the land use feature elements and rainwater sewer pipe elements. The different part is we added storm drainage so that we can faithful reproduce the complicate urban land use feature in detail.

The drainage system between the surfaces and the sewer system is based on a concept called "dual drainage", where urban drainage is modeled as two dynamically interconnected networks, and manholes function as points of flow exchange between them[2]. Fig.2-3 shows the schematic of the rainfall-runoff process by considering the rain drainage route. GIS data in this schematic is defined as urban landscape GIS delineation. Besides, for constructing urban landscape GIS delineation, GIS data has to include peripheral line of building, block and street boundary line, river boundary line, rainwater drain pipe network, digital elevation model, land use information and so on. These kinds of data are called the foundational urban landscape GIS delineation.

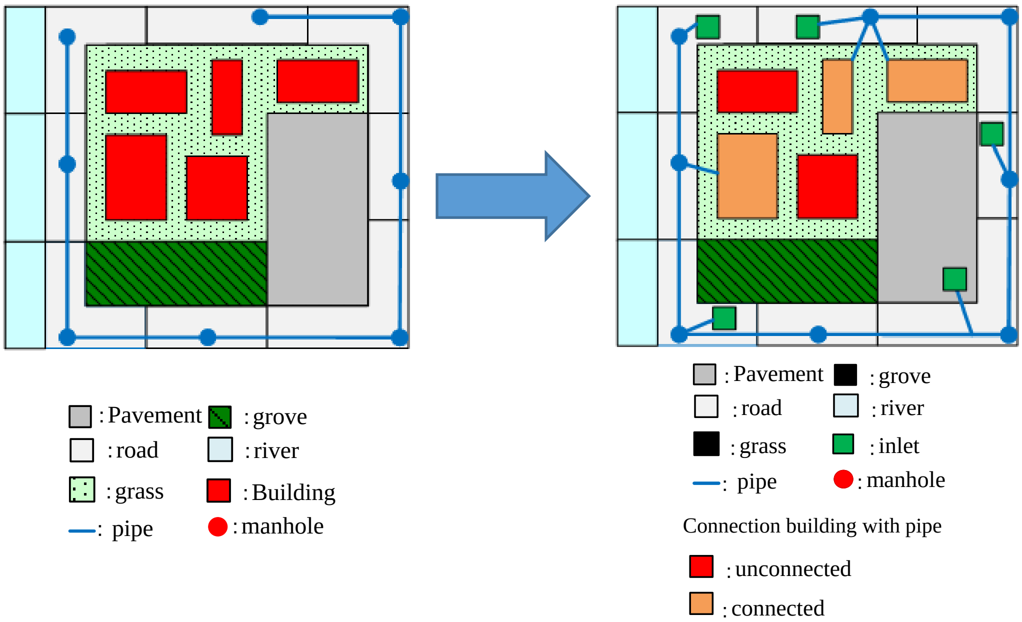

Fig.2-2 difference between the past data and the data be built in TSR Model

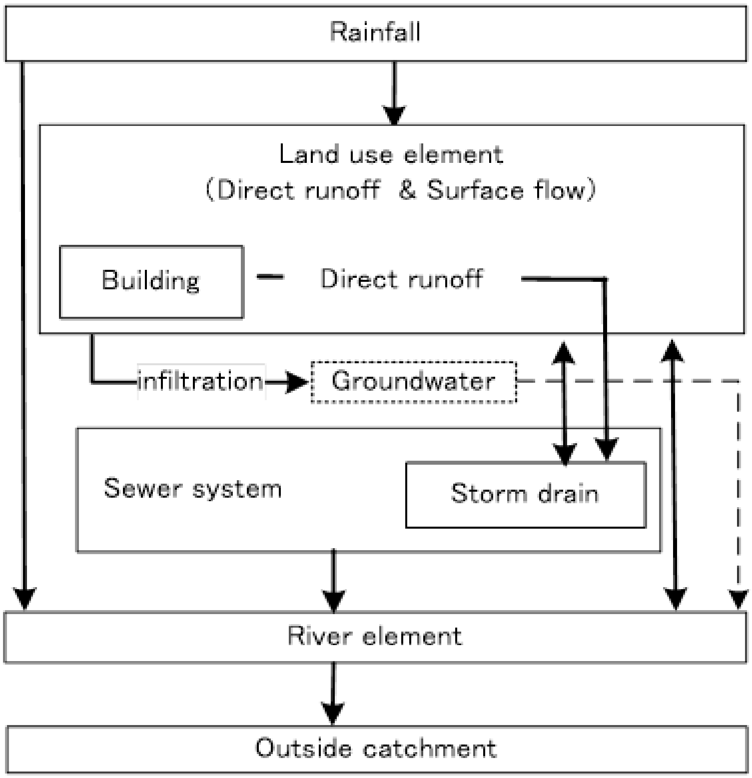

Fig.2-3 schematic of the rainfall-runoff process

During the simulation in this study, for rainfall in flowing area, based on pervious area and impervious characters, set the water depth with calculate the rainwater which over infiltration capacity by summing the original existed urban landscape water depth and inflow and outflow rate from around. The paragraph describe the basic formula of hydraulic and hydrological model in Storm Runoff Model.

In order to calculate the direct runoff, for practical estimation of rainfall excess, initial loss and continuing constant loss rate method[3] is used. Impervious surface includes land use classes building, road and parking lot, whereas class grove, grass and athletic field are considered pervious. In an impervious surface, the only rainfall loss is the initial loss, which is mainly depression storage[4]. Rainfall onto an impervious surface becomes effective after it exceeds the initial loss. It is expressed mathematically as Eq. (1).

$$r_e(t) = \begin{cases} 0 & (\sum r(t) \le L_i) \\ r(t) & (\sum r(t) > L_i) \end{cases} \tag{1}$$

Where *r(t)* denotes rainfall intensity at time *t*(s), *re(t)* effective rainfall rate (m/s), *Σr(t)* cumulative rainfall (m) and Li initial rainfall loss for land use class *i* (m).

As shown in Fig.2-3 (the schematic of urban landscape GIS delineation and the assumed flow processes), in land use segments inside block elements, direct runoff from a non-building segment to an adjacent block segment is assumed. The direct runoff on a building segment is as follows. Although rainfall on buildings usually runs off to the sewer system through a gutter, it is rare to have information on the connection between a building and the sewer system.

In the TSR model, the kinematic wave model[5] is applied to calculate the flow from a building segment to the nearest road or river segment (Eqs. (2) and (3)). Since the actual shapes of individual buildings are sometimes complicated, the shape (flow distance x_b and flow width B) is supposed to be square with the same size as the actual segment.

$$\frac{\partial h_b}{\partial t} + \frac{\partial q_b}{\partial x_b} = r_e \tag{2}$$

$$q_b = \alpha {h_b}^{\beta} \quad (\alpha = \sqrt{\sin\theta}/N_b \ , \beta = 5/3) \tag{3}$$

Where q_b denotes the discharge per unit width from the building (m^2/s), h_b the flow depth (m) and x_b the distance along the building (m). In (3), α and β are constants related to slope and surface roughness, θ the slope of the building (rad) and N_b is the equivalent Manning's roughness coefficient (s/m$^{1/3}$).

On a pervious surface, rainfall losses consist of an initial loss *Li* and an infiltration loss *Ii* for each land use class *i* [4]. The initial loss *Li* is equivalent to the sum of initial infiltration loss and depression storage. After the cumulative rainfall amount exceeds the initial loss, rainfall intensities in excess of the final infiltration capacity become effective. Therefore, the rainfall excess rate for a certain land use class is expressed as follows.

$$r_e(t) = \begin{cases} 0 & (\Sigma r(t) \le L_i) \\ r(t) - I_i & (\Sigma r(t) > L_i) \end{cases} \tag{4}$$

For surface flow, in order to calculate the discharge in surface component, one-dimensional unsteady flow without convective acceleration is assumed according to Eq. (5). Water level changes in the surface segments are computed by considering the effective rainfall and outflow/inflow from manhole elements in addition to the outflow/inflow from surface segments. After calculating water storage, the water depth is obtained by Eq. (6).

$$\frac{\partial Q_s}{\partial t} + gA_s \frac{\partial H_s}{\partial x_s} + \frac{g n_s{}^2 Q_s |v_s|}{R_s{}^{4/3}} = 0 \tag{5}$$

$$\frac{dh_s}{dt} = \frac{\Sigma Q_s + \Sigma Bq_b + \Sigma Q_{div} + r_e Area_s}{Area_s} \tag{6}$$

Where *Qs* is the surface discharge (m^3/s), As the surface flow cross sectional area (m^2), H_s (= z_s + h_s) the surface water level (m), z_s the surface elevation (m), h_s the surface water depth (m), x_s the longitudinal distance along surface segment (m), n_s the surface Manning's roughness coefficient (s/m$^{1/3}$), v_s the velocity of surface flow (m/s), R_s the surface hydraulic radius (m), *B* the width of building segment (m), Q_{div} the discharge to/from manhole from/to surface (m^3/s) and Areas the surface area (m^2) (excluding the building area in block segments).

The numerical analysis technique used for the surface flow, as well as for the calculations of sewer pipe flow and river flow described below, is the unsteady flow equation by the explicit finite difference method[6] used with the leapfrog calculation method[7].

For sewer pipe flow, the runoff in a sewer is usually in the state of free surface flow. However, in the case of a storm, both free surface flow and surcharged flow occur, and their regions vary temporally and spatially. In order to describe these processes in detail, a particular model for sewer pipe flow with surcharge is required and here dynamic waves are used to describe both free surface flow and surcharged flow. For the surcharged flow, the technique based on the assumption of a hypothetical slot is applied[8)]. In a pipe segment, the water flow is obtained considering the water levels in the manholes located upstream and downstream, respectively. The equation of motion without convective acceleration and continuity of the slot model is applied as Eq. (7).

$$\frac{\partial Q_p}{\partial t} + gA_p\left(\frac{\partial H_m}{\partial x_p}\right) + \frac{g{n_p}^2 Q_p\left|v_p\right|}{{R_p}^{4/3}} = 0 \tag{7}$$

Where Q_p is the pipe discharge (m^3/s), A_p the pipe flow cross sectional area (m^2), H_m the manhole water level (m), x_p the distance along pipe (m), np the pipe Manning's roughness coefficient (s/m$^{1/3}$), v_p the velocity of pipe flow (m/s), R_p the pipe hydraulic radius (m).

In a manhole, the storage quantity and water level are calculated by Eq. (8) and Eq. (9) respectively. The storage is based on the size of the manhole and its upward connection according to

$$\frac{dS_m}{dt} = \sum Q_{div} + \sum Q_m \tag{8}$$

$$H_m = f_{mh}(S_m) \tag{9}$$

Where S_m is storage quantity in a manhole and connected pipe (m^3), Q_m the flow from/to the connected pipe (m^3/s) and f_{mh} a function relating storage to water level in the manhole (m).

When the water level in a manhole exceeds ground water level, water flows out and inundates the associated surface segment. The discharge between a manhole and a surface segment is evaluated according to Eq. (10).

$$Q_{div} = \begin{cases} \dfrac{f_{mv}(H_m) - f_{mv}(H_s)}{dt} & \text{(outflow from manhole)} \\ \mu Area_m \sqrt{g\Delta h_s} & \text{(inflow to manhole)} \end{cases} \tag{10}$$

Where f_{mv} is a function relating manhole water level to volume, μ a coefficient and A_{ream} the manhole area.

For river flow, the river channel flow considering the inflow from the rainfall and sewer pipes, as well as the side inflow from surface segments, is calculated by the equations of motion and continuity as Eqs. (11), (12).

$$\frac{\partial Q_r}{\partial t} + \frac{\partial (Q_r{}^2 / A_r)}{\partial x_r} + gA_r \frac{dH_r}{dx_r} + g\frac{n_r{}^2 Q_r |v_r|}{R_r{}^{4/3}} = 0 \tag{11}$$

$$\frac{\partial A_r}{\partial t} + \frac{\partial Q_r}{\partial x_r} = q_r \tag{12}$$

Where v_r is the velocity of the river flow (m/s), x_r the distance along river channel (m), H_r the river water level (m), n_r river Manning's roughness coefficient (s/m$^{1/3}$), R_r the river channel hydraulic radius (m), A_r the river flow cross sectional area (m^2) and q_r the cumulative discharge from sewer system and surface segments to river segment in addition to rainfall (m^3/s).

Reference of chapter 2

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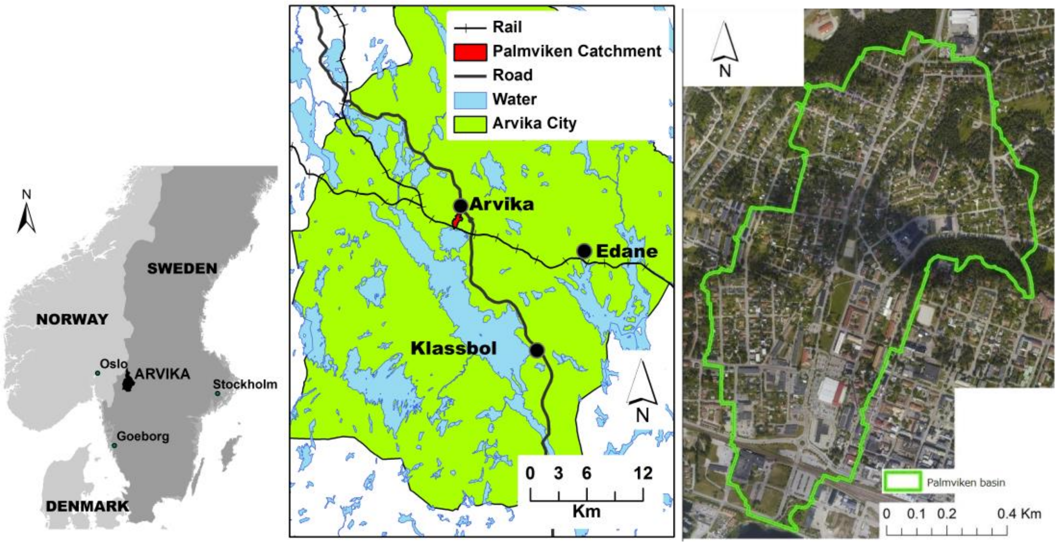
Chapter 3 MODEL APPLICATION TO THE PALMVIKEN WATERSHED IN SWEDEN

In this chapter, showing the specific information of Arvika in Sweden and data used which was described through the photos and maps by doing the field observation. Describe the Sewer characteristic of the sewer system in Arvika.

3.1 Study area

The study area selected for the model application is a small urban watershed in Arvika, in the southwest of Sweden. It is also be researched in the Climate Proof Areas Project which launched by North Sea five countries (Netherland, Germany, Switzerland, Belgium, England)[1)]. As showing in Fig.3-1. Arvika is an urban area in Arvika Municipality in western Värmland County. Arvika's urban center lies on the north side of Kyrkviken, which is a distinct part of Lake Glafsfjorden. The study watershed will be termed Palmviken watershed and Fig.3-1(c) shows this watershed in some detail. The Palmviken watershed area is ~0.92 km^2. It is essentially residential area with some minor parks, groves, fields, etc. Concerning the land use, ~47% of the surface is impervious[1)].



(a) (b) (c)

Fig.3-1 Location of the Palmviken watershed in Arvika Municipality, Sweden (a-b) and overview of the Palmviken watershed (c)

In the 1990s Arvika, floods have occurred almost regularly: in 1993, 1995, 1998 and 2000, to mention the most notable ones. With the exception of the 1995 flood, most recent floods have been induced by rainfall in summer or autumn, whereas the snowmelt-induced spring flood has traditionally been the largest flood of the year. The year 2000 was quite extraordinary, and contained two distinct floods[2)]. Not surprisingly, 2000 emerged as the year with the highest average precipitation over all of Sweden, since measurements began in 1860. (As the Photos 3-1, 2, 3 showing)

During recent years, Arvika has been subjected to heavy storms. Extensive amounts of rain caused great problems when drained into the storm system and hundreds of basement have been flood. For example, in summer, 2006 a high-intensity storm event in Arvika caused street flooding and 30-40 basements were damaged. Almost 120 basement flooded in Arvika Municipality.

Photo 3-1 Flood damage in Sweden 2000[3)]

Photo 3-2 Flood damage in Sweden 2000[3)]

Photo 3-3 Basement flood damage[4)]

3.2 Sewer pipeline system in Arvika

In this study, by doing the field observation (Fig.3-2), we get individual drainage condition of the rainwater from the houses. Photos 3-4~3-8 showing the reality condition of rainwater pipe connection in Arvika.

Fig.3-2 overview of the field survey in Arvika

Photo 3-4 rainwater pipe condition in Arvika

Photo 3-5 rainwater pipe condition in Arvika

Photo 3-6 rainwater pipe condition in Arvika

Photo 3-7 rainwater pipe condition in Arvika

Photo 3-8 rainwater pipe condition in Arvika

3.3 Use software (ArcGIS)

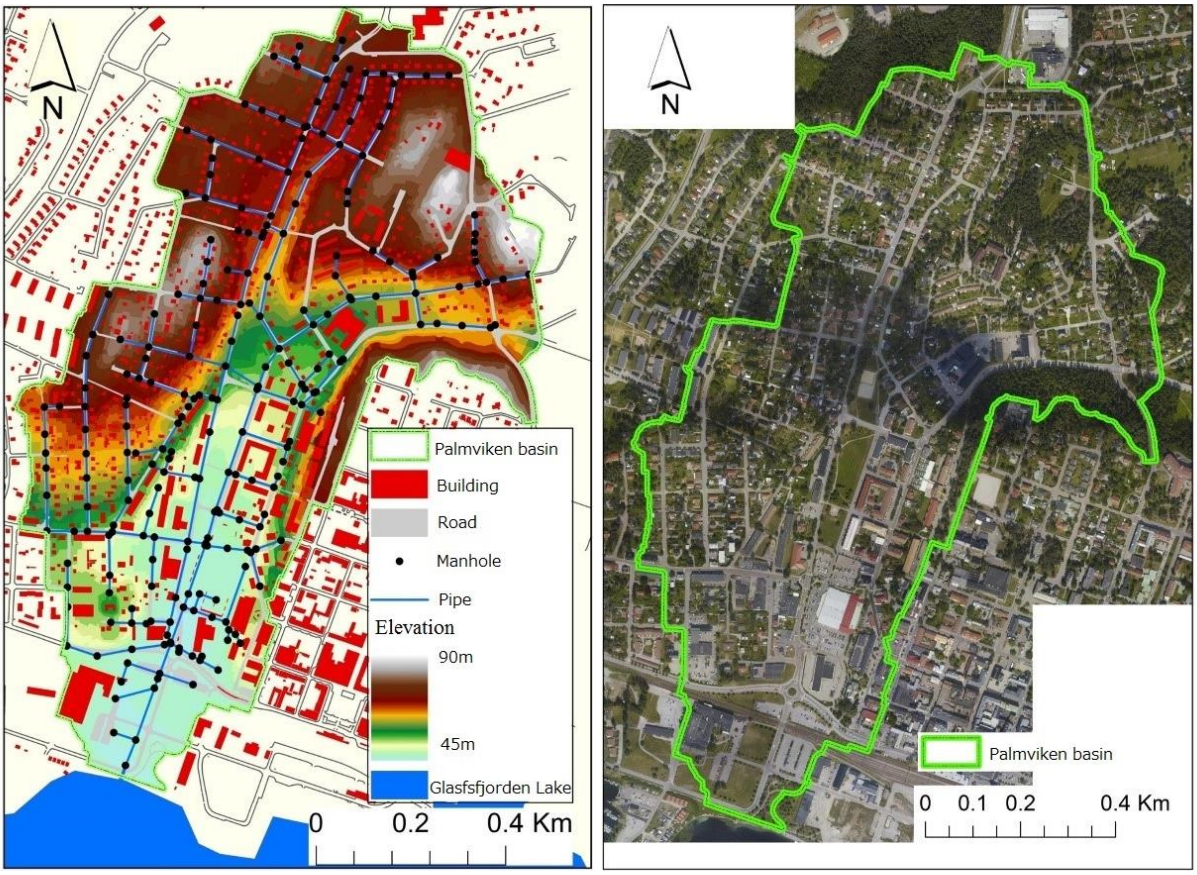
GIS data processing in the present study carried out using the ArcGIS of ESRI. GIS（Geographic Information System: It is a generic term for software family[5]. Desktop, server, mobile, is an integrated platform that can be used in common use of the available GIS software and immediately available GIS content / services in a wide range of environment. Many tools are provided in this software. For example the editor tool for manually dividing features, some other tools are for segmentation/comprehension of features and coordinate processing.

Besides, it can create own automatic editing function of GIS data using VBA (Visual Basic for Applications) macro. By using the Arc Toolbox, create the block element from closed block boundary line. For unclosed block boundary line, we use macros to extract the target boundary line and then let it automatically make modifications such as adding lines to close the boundary line.

3.4 Modeling of urban watershed

(1) Fundamental GIS data

Fig.3-3(a)-(b) shows the urban landscape GIS delineation of Palmviken watershed has been built. The data was gotten from Arvika Municipality. Fig.3-3(b) shows aerial photograph of the building and of the road's arrangement, location information of the rainwater sewer pipe (Vector type GIS data) and elevation data of the resolution 1 m (DEM). As there are no design materials of rainwater drainage system (Fig.3-3(a)), we use the rainwater sewer pipe data which are got by field observation after the flood damage in July, 2006.



(a) (b)

Fig.3-3 Foundational urban landscape GIS delineation (a) and Aerial photograph (b)

(2) Urban landscape GIS delineation has been built

Fig.3-4 shows advanced urban landscape GIS delineation which is used in this proposed model. It is composed of land use element, river element and rainwater sewer pipe conduit element. In this model, object of study is flood runoff, so the rainwater underground is not be considered.

Land use element includes building, road, pavement space, green space, boring lawn ground and other 6 types. With the reference to the aerial photograph and ground level data divide the urban environment into its smallest, perfectly homogeneous element. The total element we built is 18,081. Impervious area rate is about 47%. The rainwater sewer pipe element (Fig.3-4) is constructed to identify by doing field observation of pipeline, manhole, street inlets and connect condition of the house rainwater pipe.

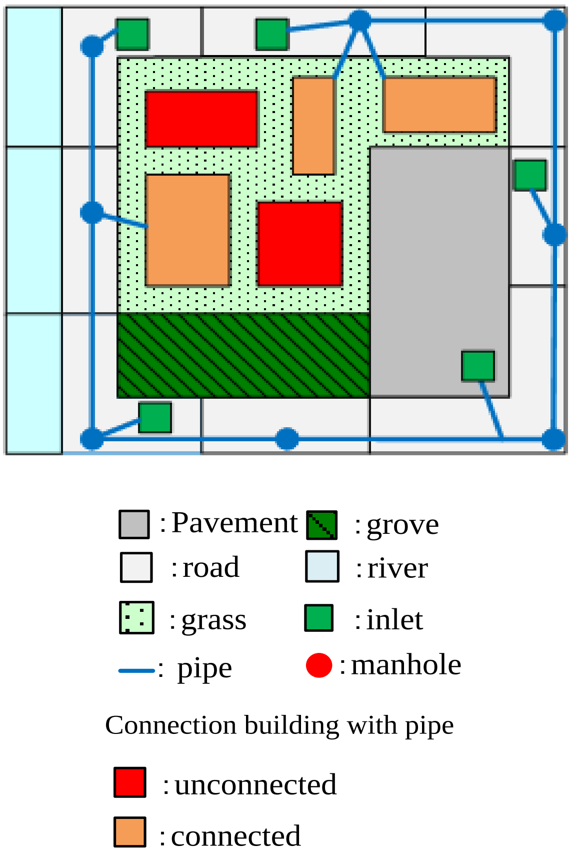


Fig.3-4 Urban landscape GIS delineation

(3) The construction of urban landscape GIS delineation

In order to reproduce the route of rainwater as faithful as possible, the urban landscape GIS delineation is constructed by using the aerial photograph. Moreover we conducted the field observation to get the information about the rainwater runoff from the houses whether connected to the rainwater sewer pipe and the location of the street inlets.

The GIS data setup of construction for the advanced urban landscape GIS delineation is showing below (Fig.3-5). In order to apply for a small urban watershed in Sweden, in the first place, the foundational GIS data is provided by Arvika Municipality, and then, we checked each sewer connection and inlets information by doing the field observation. Lastly use these data, we constructed advanced urban landscape GIS delineation.

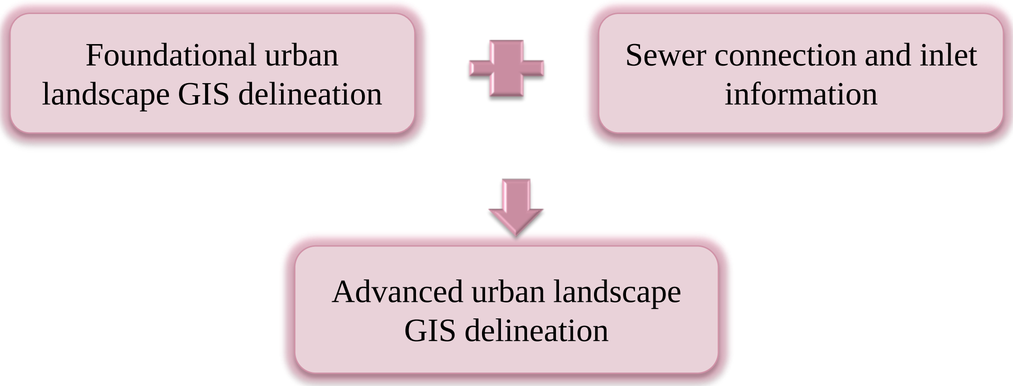


Fig.3-5 Construction of the urban landscape GIS delineation

Table 3-1 below showing the number of each element we built. Road element is 4,663, impervious area is 3,539, houses is 691, and pervious area is 9,176. The total element we built is 18,081. The numbers of rainwater pipe, street inlets and manholes are 1,841, 319 and 947 respectively. The number of houses which have connection with rainwater sewer pipe is 496, about 80% of all 691 houses. It is takes about 92% when being converted as area ratio.

Table 3-1 Number of each element

Element		**Number**	**Area (m^2)**
Road		4,663	167,372
	Impervious area	3,539	147,434
	Houses	691	122,259
	Pervious area	9,176	483,582
	Total	18,081	920,647

(4) Land use feature elements

The road and pervious - impervious feature which constitute the land use element, with reference to the aerial photograph and ground level data, urban landscape GIS delineation is used to divide the urban environment into its smallest, perfectly homogeneous elements, including sewer network systems that are hydraulically connected. These elements could reflect urban watershed regional characteristics in urban landscape GIS delineation.

The parking area takes most part of impervious feature but boring lawn ground, forest and bare land take most part of penetration feature. When splitting the city block to the pervious - impervious feature by aerial photograph, keeping the feature area under 100 m^2, splitting to the small elements with the consideration of feature characteristics.

For the road feature, making Small elements of road is in need to consider the characteristics of road width in the linear direction if it has median strip and sidewalk. Fig.3-6 shows the land use feature element in the advanced urban landscape GIS delineation were constructed.

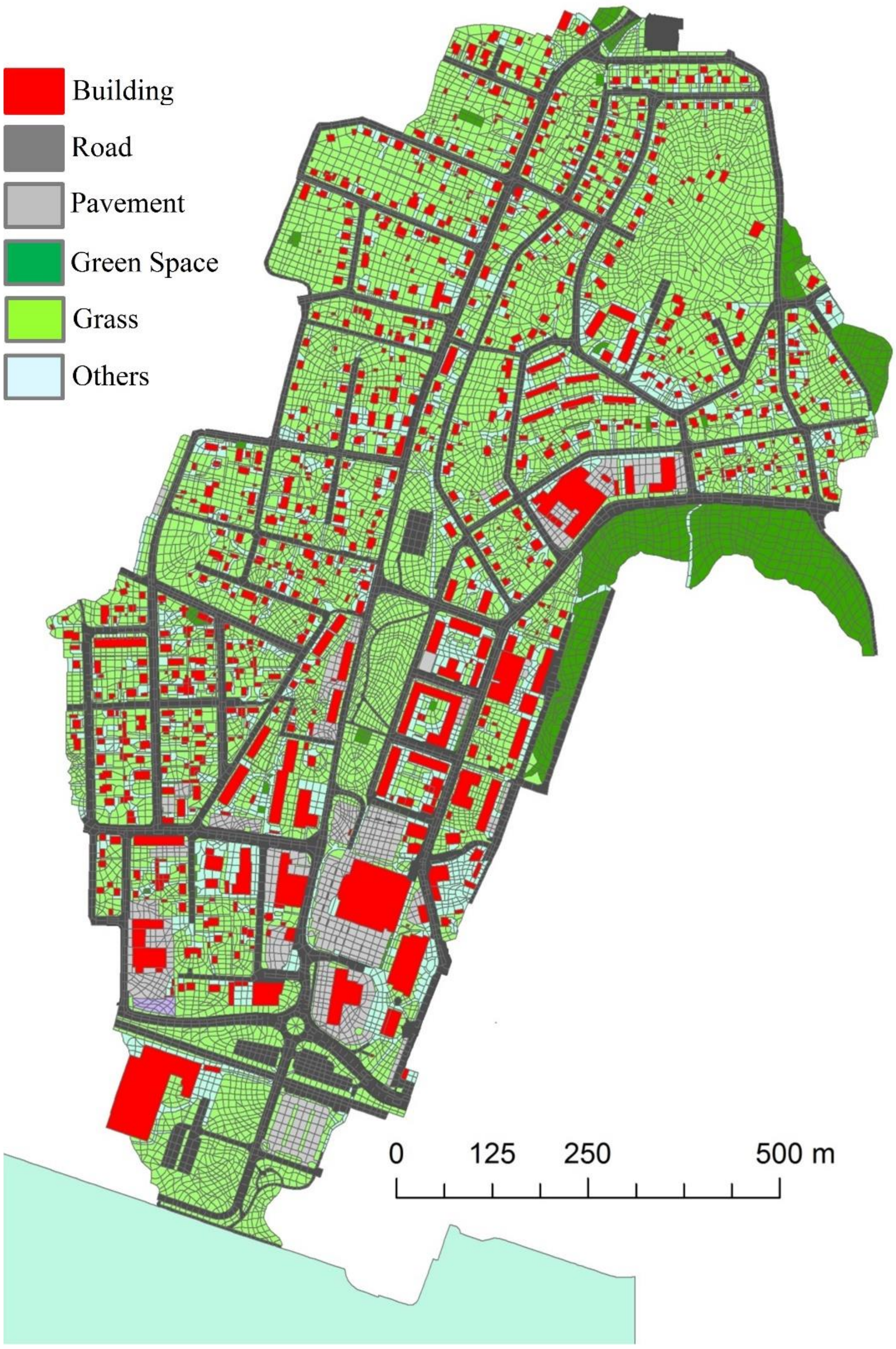


Fig.3-6 land use feature element

(5) Rainwater sewer pipe conduit elements

Fig.3-7 shows the difference of rainwater sewer pipe element between the original data and Modified data. When compared with the original data in TSR model, the advanced urban landscape GIS data in this study not only consider the manhole and sewer pipe but also add the information of street inlets, house inlets, sewer connection and so on. As a result, the number of street inlets element we built is 319, houses inlets is 575, pipe element is 1,841, and manhole element is 947. Compare with the number in original data, almost 4 times bigger.

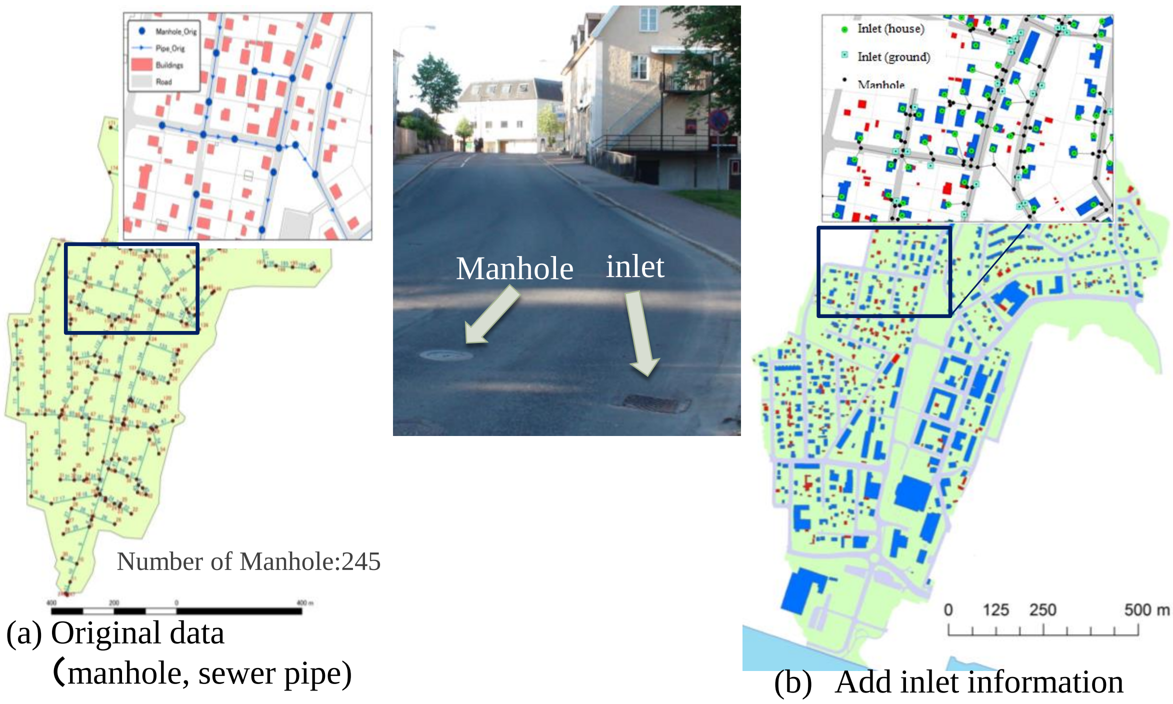


Fig.3-7 Rainwater sewer pipe element in original data and Modified data

The obtained GIS format of rainwater sewer pipe conduit data including the manhole information with ground level, bottom high, pipe length, pipe diameter, pipe bottom height of two sides as the information of pipe section are inputted. In this study, setting the information of connecting pipe between the street inlets and rainwater sewer pipe is necessary, so the pipe diameter was set as minimum 10 m which is used in the field. The slope of pipe was set as 1/200 based on several measurement samples. Besides, by doing field observation in Arvika, we checked the sewer connection of each house and the location of each inlet. And use these data we built the rainwater sewer pipe element. The street inlet reflects the identify rainwater sewer pipe conduit data. Fig.3-8 shows that the rainwater sewer pipe conduit elements be constructed among the advanced urban landscape GIS delineation.

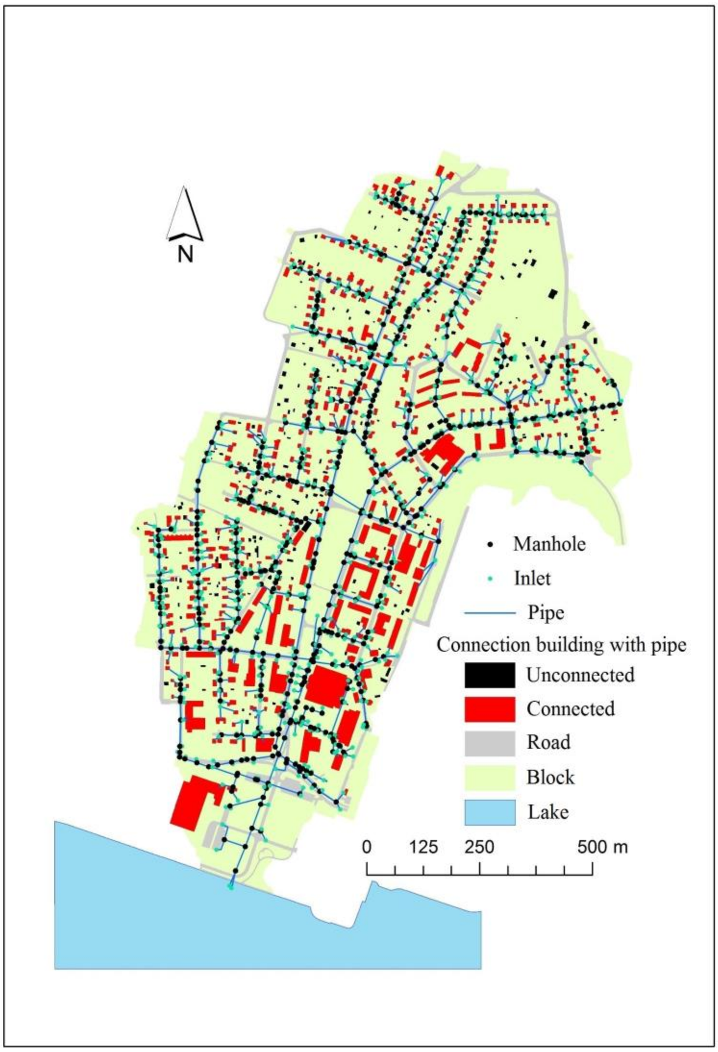


Fig.3-8 Rainwater sewer pipe conduit elements

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Chapter 4 ANALYSIS BY THE STORM RUNOFF MODEL

Chapter 4 contains the storm runoff model which application to the study watershed in Arivika (Sweden), then described every important parameter be used in the model and the analysis the results.

4.1 Parameter setting

In global perspective, a growing number of floods in urban areas is evident[1)] and the problem of urban flooding is further expected to increase in the future. One obvious reason is today's rapid urbanization in many parts of the world, which is not always accompanied by a sufficient increase of the sewage system capacity. Another somewhat more speculative reason is the increased frequency of high rainfall intensities as a consequence of heat island phenomena and climate change, which has been indicated in several studies[2), 3)].

Heavy rainfall and poor drainage facilities cause inundation in urban watershed. In Avrika (Sweden), urban rainfall intensity is relatively small so that slight increase in rainfall intensity may cause problems especially in rainwater sewer drainage system. The annual rainfall in Sweden is around 600 mm (Tokyo 1600 mm), 10 years 60 minutes probable rainfall is 24 mm (Tokyo 52 mm) [4)]. It reflected the rainfall characteristics in Sweden, street drain has not been set basically and that most of the rainwater has flown into rainwater drain pipe through the street inlet directly. Therefore the improvement of rainwater drainage facilities and assessment of inundation risk assessment through inundation simulations are important for flood control[1)]. With climate changing and the increase of the rainfall, it is necessary to concern how to deal with the flood damage increasing in urban watershed.

To properly evaluate the damage-reducing effects of current or planned structural measures (such as infiltration and storage facilities or permeable pavements), storm runoff models are required that take full advantage of today's geographical data sources and processing tools. A highly explicit and spatially distributed strategy in urban watershed modeling is crucial for accurately evaluating the effectiveness of various measures and for facilitating stakeholder communication.

Table 4-1 below shows the parameters setting in the Storm Runoff Simulation Model in this study. These parameters were set as the value of the standard number in the literatures relevance. Due to each land use pervious character of the watershed in this study has not been obtained, as the land use elements in the policy of advanced urban landscape GIS delineation, boring lawn ground, forest, bare land and other permeable feature were set as the same type. The building feature, rode feature and other three types were set as the impermeable feature.

For the initial loss showing in the Table 4-1, according to the character of the pervious and impervious, we sets the rainfall of initial rainwater as the loss. Setting certain infiltration capacity in the permeable feature, if the precipitation is over the infiltration capacity, the excess precipitation will be treated as direct runoff. According to application example of Street Network Model by YIKEUCHI[5)], the roughness coefficient of surface stream was set as the value considering the roughness coefficient of rainwater sewer pipe as friction loss or manhole loss etc.

The lake level which set as the downstream side condition of rainwater sewer pipe, planned value is 46.5 m. In the event in July 2006 which the rainfall caused the houses generated flood damage, by giving 10 minutes rainfall from the rainfall observation site where is at 3 Km north of watershed. The analysis about the flow of ground surface and rainwater sewer pipe is performed at about 0.2 second intervals.

Table 4-1 Parameters of TRS Model

Parameters（units）	Value	
Initial loss: L_i (mm)	Impermeable feature	2.0
	Permeable feature	4.0
Infiltration capacity: I_i (mm/hr)	Green space and grass	20.0
	Others	5.0
Ground surface roughness: n ($s/m^{1/3}$)	Among road	0.043
	Others	0.067
Pipe roughness: n ($s/m^{1/3}$)		0.013

4.2 Inundation Analysis of the heavy rain in 2006

In the flood runoff analysis, the proposed model considers about the exact storm drainage route of houses. The previous model are set the rainwater from houses flowing out from the road nearby. In the following analysis, we set the proposed model as Case A, Case B also set as the proposed model which considering the street inlets, Case C as previous model which without considering any inlet.

Figs.4-1 and 4-2 describe the rainfall runoff results of the proposed model. Especially Fig.4-2 shows storm loss as hydrological change of the whole watershed, accumulative infiltration amount, ground surface storage discharge, pipeline storage discharge and the time-series variations of accumulative outflow.

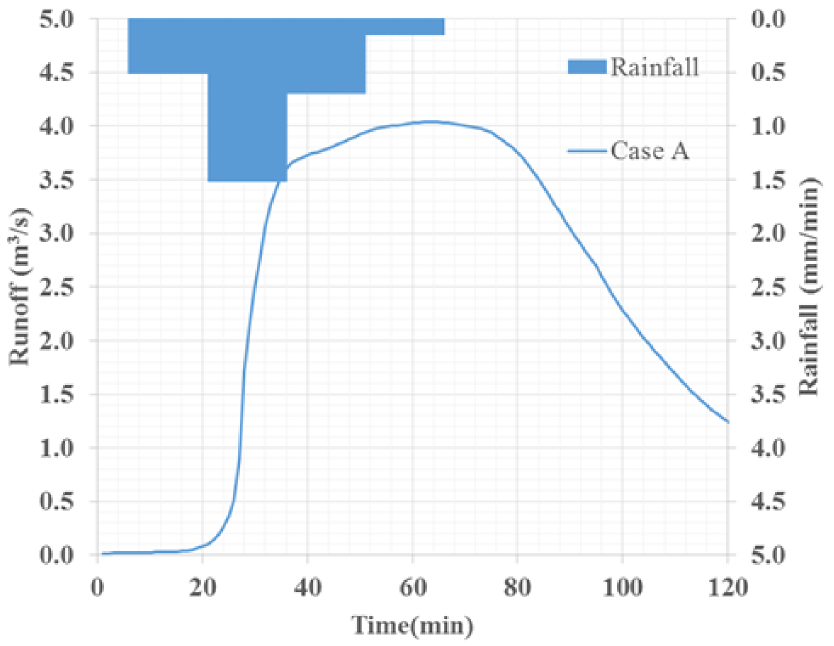


Fig.4-1 Discharge of Case A

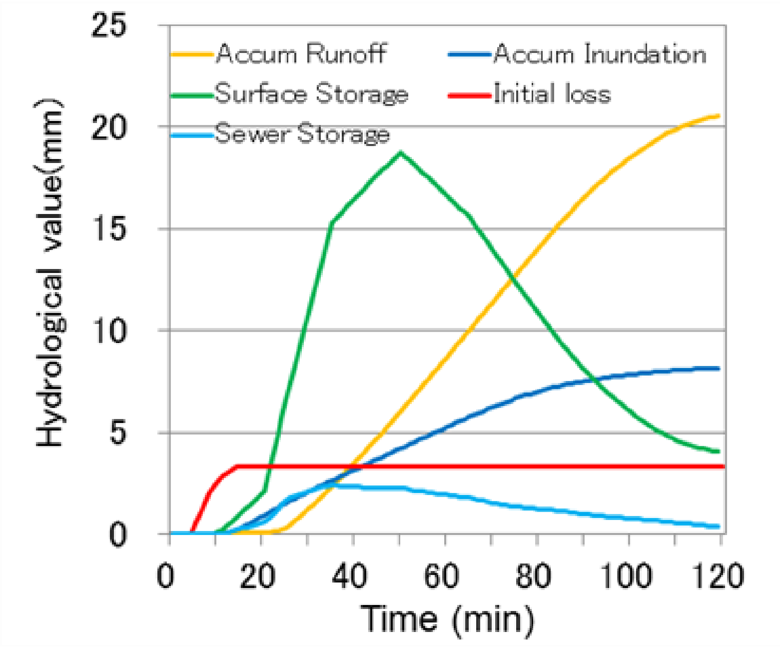


Fig.4-2 Result of the rainfall in 2006

In order to compare with previous model, then we simulated in each case. Fig.4-3 shows the simulate results of three cases. According to the number of pipeline the discharge peak value of Case A is the highest, Case C is the lowest. From these results, it could be read that, the connection between the houses and rainwater pipes, the existence of the street inlets on the ground surface, influencing the discharge to the lake. Besides the runoff ratio in Case A is 68.1% with adding the 42.3 m precipitation and 25.0 mm storage discharge which include the outflow, ground surface and pipeline.

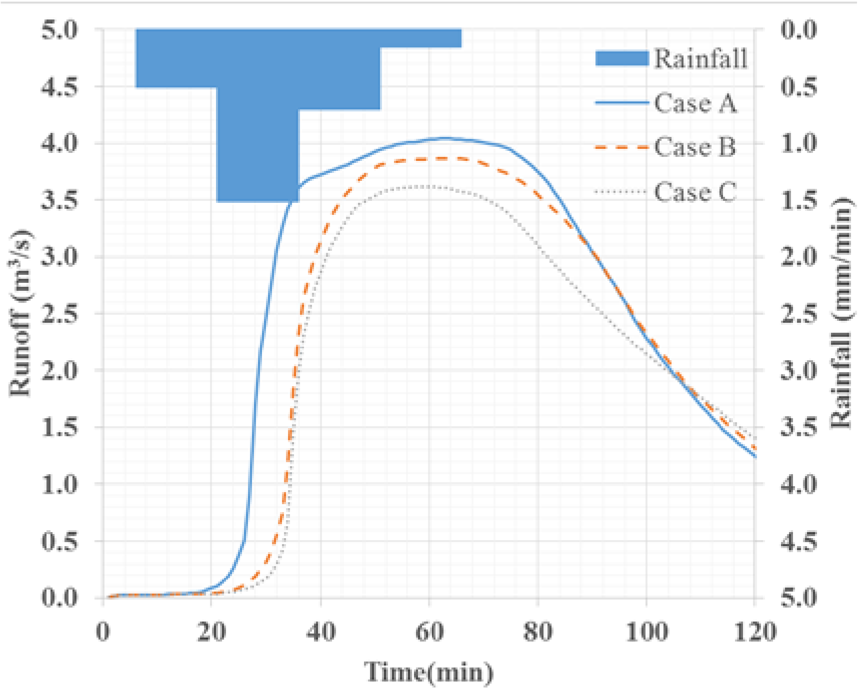
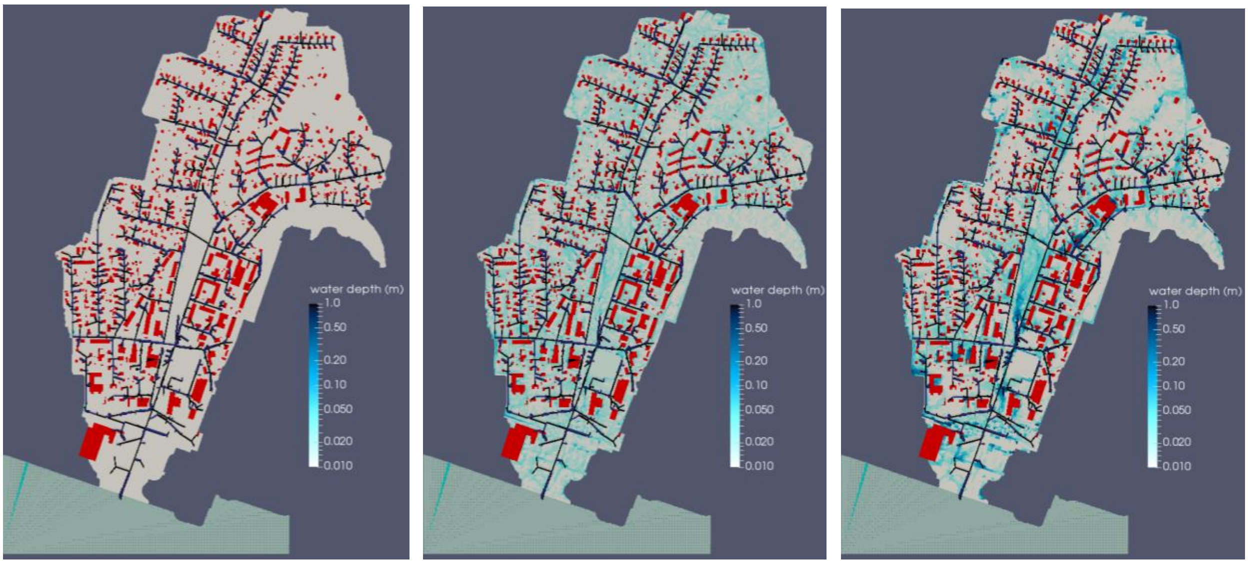


Fig.4-3 Discharge of the rainfall in 2006

Figs.4-4 shows the each flood depth condition of Case A at 20 minutes, 30 minutes and 50 minutes respectively. It could read that, the inundation depth is changing with the time fly. When it got 20 minutes, it just has several places increase the water depth, but when the time going to 50 minutes, the inundation condition got to the peak, the area on the middle lower part become serious.



20 minutes 30 minutes 50 minutes

Fig.4-4 Flood depth condition of Case A

What's more, in order to know the effectiveness of the proposed model and compare with the previous models, then we show the inundation condition of other cases. Fig.4-5 on the below shows the maximum inundation depth on the ground surface, especially the manholes and street inlets with overflow water depth more than 0.1 m and the pipeline used for the analysis were showed in each cases. The number of pipeline from Case A to Case C is 1841, 1268, 588 respectively. Especially in Fig.4-5(a), shows the houses that had flood damaged by the rainfall in proposed model of this study.

Area A is the lower watershed, Area B is the upper watershed. As Figs.4-5 showing, many of the ground surface overhead flooding were concentrated near lower watershed inside the Area A. The flood depth and range is Case A bigger than Case B， Case B bigger Case C. In the case of proposed model Case A, due to the rainwater through the houses inlets (the houses have connect with rainwater pipe) and street inlets on the ground surface flow to the lower watershed. It lead the inundation depth of manholes and street inlets in the lower watershed increased concentrated at Area A, so as the discharge (in Fig.4-3) showing, the flood arrival time in Case A has become faster and peak value of discharge get higher than other Cases.

Contrast with the inundation data which got from Arvika Municipality, the inundation range in this simulation is notarized roughly match with the Area A, though the measurement information of the flooded area in this study has not been obtained.

(a) Case A (b) Case B (c) Case C

Fig.4-5 Maximum inundation depth and inundation manholes

Table 4-2 is counting the number of houses with each inundation depth. In the table, the left side showing each classes of inundation depth, the middle side shows the number of houses, the left side describes the number of basement be flooded.

The maximum inundation depth of each surrounding house have been set in the proposed model, it is also showing the number of basement flooding in each inundation depth. Although when the inundation depth under 0.1 m, the proportion of basement inundation is approximately under 3%, if the inundation depth over 0.1 m, the inundation risk will exceed about 10%. Therefore it is considered that, when the flood depth of surrounding building is over 0.1 m, the risk of basement flood will dramatic increase.

Table 4-2 Number of basement inundation

Inundation depth (m)	Number of houses （basement inundation）	
Under 0.01	19	(1)
0.01-0.019	156	(1)
0.02-0.039	360	(8)
0.04-0.059	60	(4)
0.06-0.079	27	(1)
0.08-0.99	0	(0)
0.10-0.19	40	(3)
0.20-0.29	14	(1)
Over 0.3	15	(2)

In addition, because of the rainwater on the ground surface is set as inflow without any barriers in this simulation, the later simulation should pay more attention to the local situation change, though the relationship between the flooding of the manhole and basement flooding is not clear.

4.3 The runoff characteristic of rainfall in the future

The rainfall in this study is aimed to study the 10 years probability rainfall current situation (see TC) and future situation (see F3) of study watershed. The rainfall waveform is shown in Figs.4-6. Two Peak value mean that the total rainfall amount of F3 and TC are 29.4 mm, 23.9 mm, the peak rainfall are 1.66 mm/10 min, 1.27 mm/10 min respectively. Compared with TC, F3 is 12% increase of total rainfall amount, peak rainfall is nearly 30% increase at the same time. It should be noted that, F3 was get through down scale the Sweden region by the Regional Climate Model RCA3 with the result has been analyzed from Global Climate Model ECHAM5 IPCC scenario A1B in 2071-2100[6), 7), 8)].

Figs.4-6 also show the runoff from rainwater pipeline to lake. The Storm Runoff Analysis Model result was obtained by inputting TC and F3 in the proposed model. In the condition from now to the future, the peak rainfall will increase approximately 30%. Although the peak flow just increases about 30%, it was obtained that the runoff ratio will rise to 40% from 23%.

Fig.4-7 shows the runoff of each time stage. TC means the probability rainfall current situation in each year (eg. TC01 is 1 year probability rainfall), FC10 expression the future 10 years probability rainfall. As time flies and increases of the precipitation, the runoff is also showing a tendency to rise exponentially.

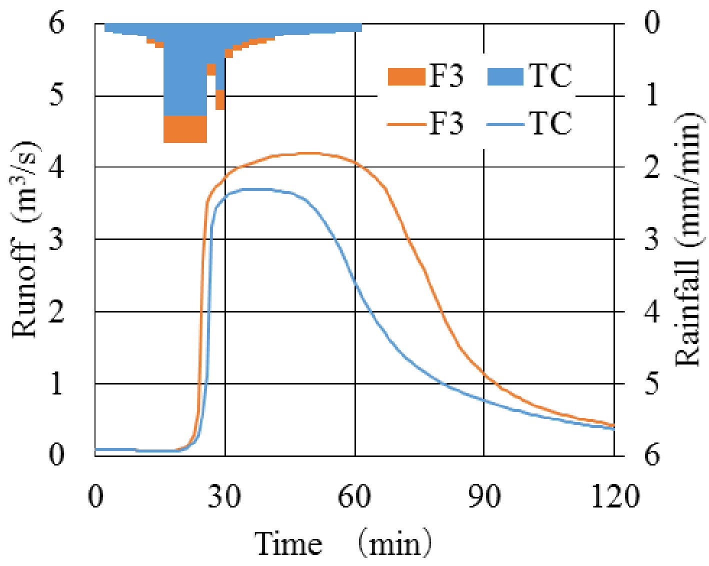


Fig.4-6 Runoff and rainfall

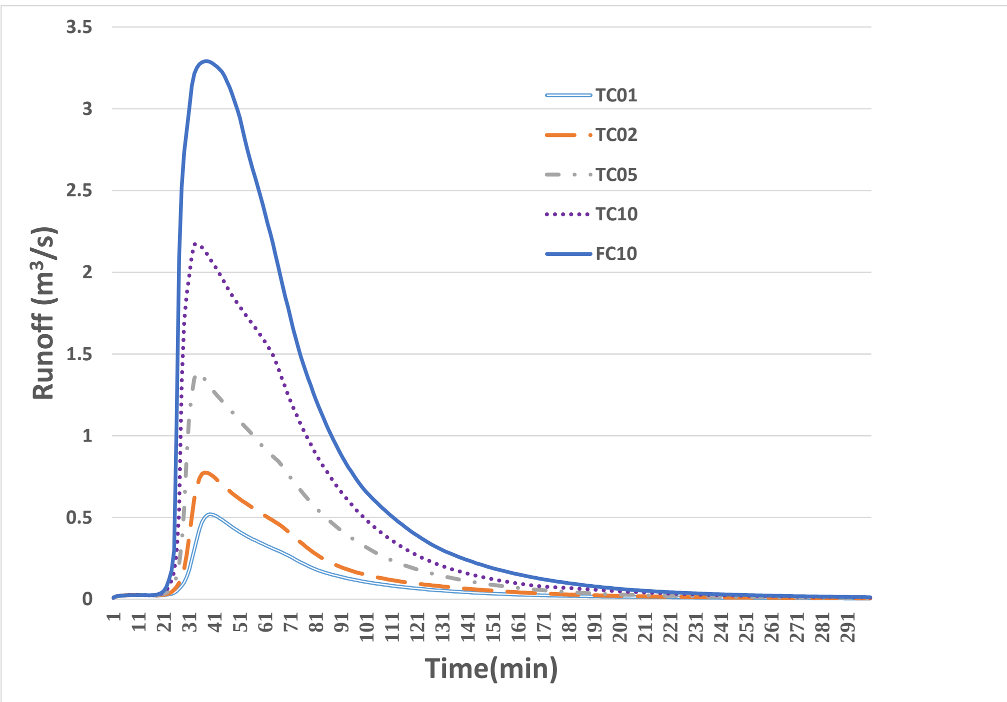


Fig.4-7 Runoff of each probable rainfall

Fig.4-8 shows the distribution of manholes and street inlets which overflow water depth more than 0.1 m. For rainfall F3 in the future, the overflow manhole is expected to increase twice over from 31 to 64 by the current rainfall. In order to reduce the flood damage, it is very necessary to renovate the pipeline or setting up the retention basin.

Furthermore, by thinking of the runoff ratio is changing by the development of urbanization rate when planning the model. For future rainfall F3, the important thing is not only to the measures but also to pay more attention to the everyday changes of urban structure.

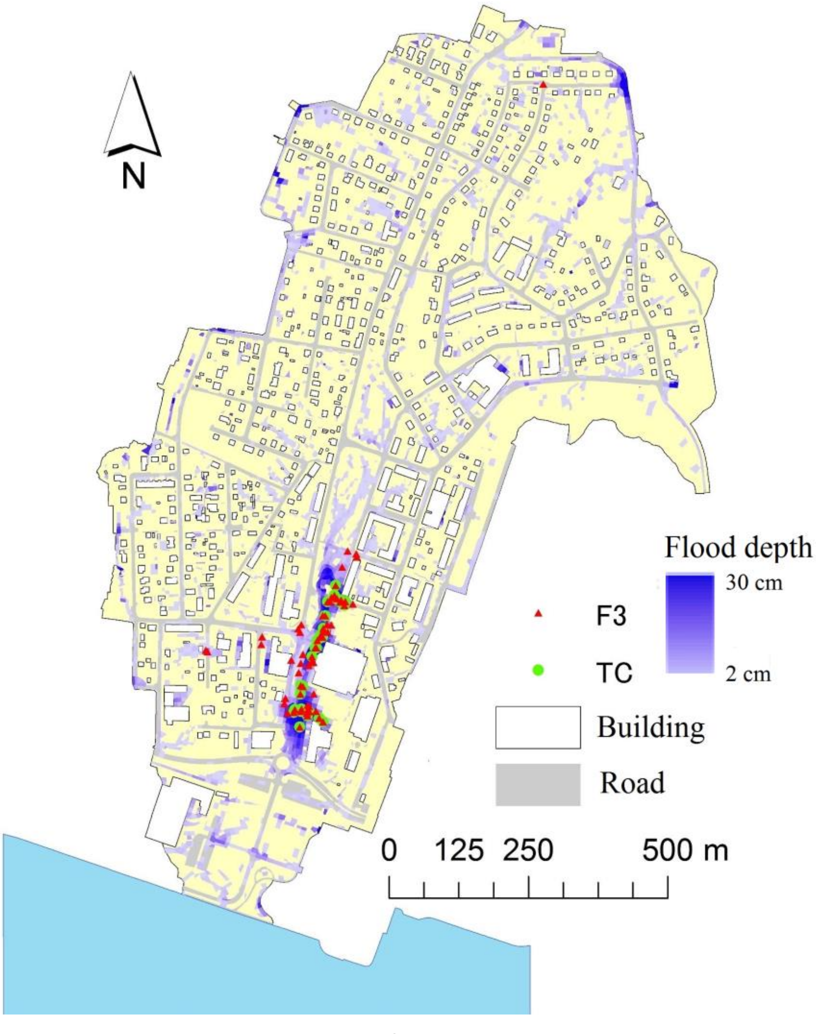


Fig.4-8 change of inundation manhole

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Chapter 5 SUMMARY AND CONCLUSION

Heavy rainfall and poor drainage facilities cause inundation in urban watershed. The improvement of rainwater drainage facilities and assessment of inundation risk through inundation simulations are considered important for flood control. With climate changing and the increase of the rainfall, it is necessary to concern how to deal with the flood damage increasing in urban watershed.

An urban watershed where the rainfall intensity is relatively small, slight increase in rainfall intensity may cause problems especially in rainwater sewer drainage system. The urban environment is characterized by its abundance of impervious surfaces (roofs, roads, parking lots etc.), from which runoff is rapidly generated as overland flow. For evaluating this slight difference in the storm runoff model, the model needs to have the explicit expression on the characteristics of urban storm runoff processes from water falling on the surface to rainwater sewer drainage system.

In order to consider individual features in the urban environment, a few models have been developed from the view point of urban morphology. Like proposed a non-grid-based GIS catchment description based on information in so-called urban databanks, which consist of cadastral parcel, building, street, sewer system and river to calculate urban unit hydrographs or employed a similar concept to develop an urban water budget model. Recently, vector-based basic GIS maps containing essentially the same information as urban databanks (except sewer system information) are becoming available[1)].

In this study, storm runoff model considering rain drainage of houses is studied which can simulate urban storm runoff and flood inundation with a vector-based watershed description, and exactly delineated the pervious and impervious land surface features. It reproducing the complicated rainfall-runoff process in urban watershed by use of landscape GIS delineation which faithfully describes the complicate urban land use features in detail like every individual building, parking lots and roads. Then modeling these impervious area to physically reproduce the rainwater runoff route. This process we called it TSR model. The model is setup for a small watershed in Arvika, Sweden where is also the Climate Proof Areas Project was promoted by North Sea five countries (Netherland, Germany, Switzerland, Belgium and England).

At first, we collected the information of foundational urban landscape GIS delineation of Palmviken watershed and the aerial photograph of the building and road's arrangement and location information of the rainwater sewer with vector type GIS data and elevation data of 1 m resolution.

Secondly, for setting up the storm runoff model, we grasping the particular land use situation and rainwater drainage route from houses by field observation to build the advanced urban landscape delineation.

At last, we applied for a small urban watershed in Sweden and investigate the useless of proposed model by doing inundation analysis with the data of flood damage event in 2006. Evaluated and examined the usefulness of the proposed model by comparing the previous models.

To conclude, we applied for a small urban watershed in Sweden and investigate the useless of proposed model from the inundation analysis with the data of flood damage event in 2006, evaluated and examined the usefulness of the proposed model by comparing the previous models. With the flood runoff characteristic and flood properties were showed quantitatively, the effectiveness of the proposed model is also be indicated.

Besides, according to rainfall probability now days and 10 years in the future, the change of rainfall and the increase number of inundation manholes are evaluated and examined. Used the proposed model, the specific scenario analysis could be completed by the flood protection measures like setting the water tank of house, improvement of the existing rainwater sewer pipe conduit and installation of detention pound and so on. In order to complete this analysis, the mutual understanding between the planer and residents is very important at the time of the decision-making process of Urban Drainage Plan.

Reference for chapter 5

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Laboratory of Hydrology
Yoko Kai